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SEVENTH QUARTERLY REPORT

FOR

DEVELOPMENT CONTRACT-HIGH TEMPERATURE PULSE FORMING NETWORK

PERIOD: 29 NOVEMBER 1960 TO 29 FEBRUARY 1961

SPRAGUE

NAVY DEPARTMENT BUREAU OF SHIPS
ELECTRONICS DIVISION

UNCLASSIFIED

CONTRACT NO. NOB SR-77598
INDEX NO. NE-008030/ST9

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SPRAGUE ELECTRIC COMPANY

NORTH ADAMS, MASSACHUSETTS

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ABSTRACT

Previous quarterly reports have outlined the need for this development contract. This report describes the work that has been done in connection with full-sized units employing a cushion of various gases above the impregnant (FC-43) in an attempt to design a network not requiring a volume-compensating bellows.

Testing during this period has been primarily directed at a solution for the problem of maintaining a high corona starting voltage over the entire operating temperature range of the network. Tests reported in the Sixth Quarterly Report have continued in conjunction with tests performed on full-sized units employing volume-compensating bellows.

Life testing of small test networks using FC-43 liquid impregnant has continued during this period. Data obtained to date from these tests have indicated that final design stress will satisfactorily meet the specification of the contract.

PART I - DEVELOPMENT TO DATE

A. Purpose

Tests during this period were primarily concerned with two approaches to the problem of maintaining a high corona starting voltage in the network after exposure to elevated temperatures.

Testing has shown that the corona starting voltage for this design is below that required by the contract unless all parts of the network are completely submerged in FC-43 liquids. It has been shown that the required submersion can be maintained by the use of some volume-compensating device. However, in the hope of finding a solution for the problem of corona other than a volume-compensating device, an attempt has been made to find a gas which could be used in conjunction with FC-43. This gas would be placed in the void created above the liquid FC-43. Because of the large coefficient of expansion of FC-43, it was found necessary to remove approximately 20% of the FC-43 from the tank. The gas which must be placed in the void created by the removal of the FC-43 must exhibit dielectric properties similar to those of the impregnant (FC-43). It is the purpose of this report to give the results of tests performed along this line of investigation.

B. Approach - Tests and Results

In an attempt to meet the corona starting voltage requirements of the contract without employing a volume-compensating device, a series of tests employing a cushion of various gases above the impregnant FC-43 have been performed.

Because of the large coefficient of expansion of FC-43, it was necessary to remove approximately 20% (at room temperature) of the FC-43 impregnant from the tank containing the network to prevent damage to both can and network caused by the high pressures present at elevated temperatures. With 20% of the impregnant removed from the tank, the corona starting voltage requirements of the contract are met only at elevated temperatures. As the unit is allowed to cool to room temperature (25°C), corona starting voltage becomes a problem because of the void which has been created by the reduced amount of impregnant present. This void causes parts of the network to be exposed to whatever atmosphere may be present in the tank. In order to meet the corona starting voltage requirements at temperatures of 25°C and lower, it is desirable to find a gas which could be used to create an atmosphere inside the tank which would exhibit dielectric properties similar to those of the impregnant.

1. Corona Starting Voltage in Various Atmospheres

The contract requires the unit to be corona-free at 13.43 KV RMS.

For the purposes of these tests, three gases were used: air, nitrogen, and hexafluoroethane. Air was used to establish a datum for evaluating the other two atmospheres.

a. Corona Starting Voltage in an Atmosphere of Air

By heating unit Z-2054, 20% of the liquid impregnant was removed, and the void created during cooling by the loss of impregnant was allowed to fill with air. The unit was then sealed at 25°C with a pressure gauge. The unit was again heated to 160°C and allowed to cool. CSV and pressure were recorded before, during, and after the heating of the unit. The following data were recorded:

CSV at 25°C and 0 psig - 6.5 KV RMS

CSV at 160°C and 14 psig - 14 KV RMS

CSV at 25°C and 4 in vac - 4 KV RMS

b. Corona Starting Voltage in an Atmosphere of Nitrogen

As before, 20% of the impregnant was removed from unit Z-2055 and the resultant void filled with nitrogen gas under a pressure of 0 psig at 25°C. The unit was then sealed with a pressure gauge. The following test was performed and data recorded:

CSV at 25°C and 0 psig (unit filled with FC-43) - 15 KV RMS

20% of impregnant removed, void filled with nitrogen at 0 psig.

CSV at 25°C and 0 psig of N_2 - 10 KV RMS

Unit heated at 160°C for 24 hours.

CSV at 160°C under 5 psig of N_2 - 15 KV RMS

Unit cooled to 25°C.

CSV at 25°C under 1 in vac of N_2 - 8 KV RMS

Unit reopened and refilled with N_2. (The reason for recharging the unit with nitrogen was to replace the nitrogen which had been dissolved by the liquid impregnant, FC-43.)

Unit heated to 160°C.

CSV at 160°C under 5 psig of N_2 - 15 KV RMS

Unit cooled to 25°C.

CSV at 25°C under 3 in vac of N_2 - 9 KV RMS

Unit Z-2055 was again tested under a nitrogen atmosphere created in the unit under a positive pressure. The following data were recorded:

At 25°C the unit was sealed under 8 psig of nitrogen gas.

Unit heated for 25 hours at 160°C.

CSV at 160°C under 18 psig of N_2 - 15 KV RMS

Unit cooled to 25°C.

CSV at 25°C under 0 psig of N_2 - 4.5 KV RMS

The low corona starting voltage at 25°C after the unit was heated to 160°C in the above test was due to the amount of nitrogen forced into the impregnant by the pressures created at 160°C (18 psig). This was discovered when the impregnant was degassed. As the nitrogen gas was removed from the impregnant, the corona starting voltage increased to 9 KV RMS. This 9 KV was recorded under the same void conditions as was the 4.5 KV RMS before degassing.

The above test was again performed but with a greatly reduced volume of FC-43. The volume of FC-43 was reduced by filling the voids located at the ends and sides of the unit with aluminum plates. Again the unit was sealed under nitrogen pressure after 20% of the reduced volume of FC-43 had been removed. The consequent ratio of void to liquid volume was equal to that of the previous test. The end results of the test were the same as before. Corona starting voltage of 25°C and under 9 in vac of nitrogen was 4 KV RMS. This low corona starting voltage was also due to the nitrogen which was forced into the impregnant by pressures created at elevated temperatures.

c. Corona Starting Voltage in an Atmosphere of Hexafluoroethane

As described before, 20% of the impregnant was removed from Unit Z-2055, and the resultant void was filled with hexafluoroethane (C_2F_6) under a pressure of 0 psig and sealed with a pressure gauge. The following test was performed and data recorded.

Because of solubility of C_2F_6 in FC-43, the original pressure of 0 psig at which the unit was sealed decreased to 9 in vac.

CSV at 25°C under 9 in vac of C_2F_6 - 9 KV RMS

Unit heated to 160°C.

CSV at 160°C under 3 psig of C_2F_6 - 15 KV RMS

Unit cooled to 25°C.

CSV at 25°C under 21 in vac of C_2F_6 - 6.5 KV RMS

The above three readings of corona starting voltage show substantial improvements over the readings taken under atmospheres of air and nitrogen, if the pressures at which the readings were taken are considered. The readings taken at 25°C after exposure to 160°C in each atmosphere were:

Air - under 4 in vac - CSV of 4 KV RMS

Nitrogen - under 3 in vac - CSV of 9 KV RMS

C_2F_6 - under 21 in vac - CSV of 6.5 KV RMS

It was shown earlier that adding nitrogen to the void under positive pressures gave a decrease in corona starting voltage. This decrease was due to the amount of nitrogen dissolved by the liquid FC-43, as was shown earlier when the liquid was degassed.

In order to show that an atmosphere of C_2F_6 gives a better corona starting voltage than does an atmosphere of nitrogen, a curve (see Figure 1) was obtained of pressure of C_2F_6 vs corona starting voltage. The curve also shows that at pressures above 3.04 psig there were no apparent increases in corona starting voltage. The highest obtainable corona starting voltage of 12 KV RMS falls below that required by the contract; therefore, testing under an atmosphere of C_2F_6, as well as under nitrogen atmosphere, was discontinued.

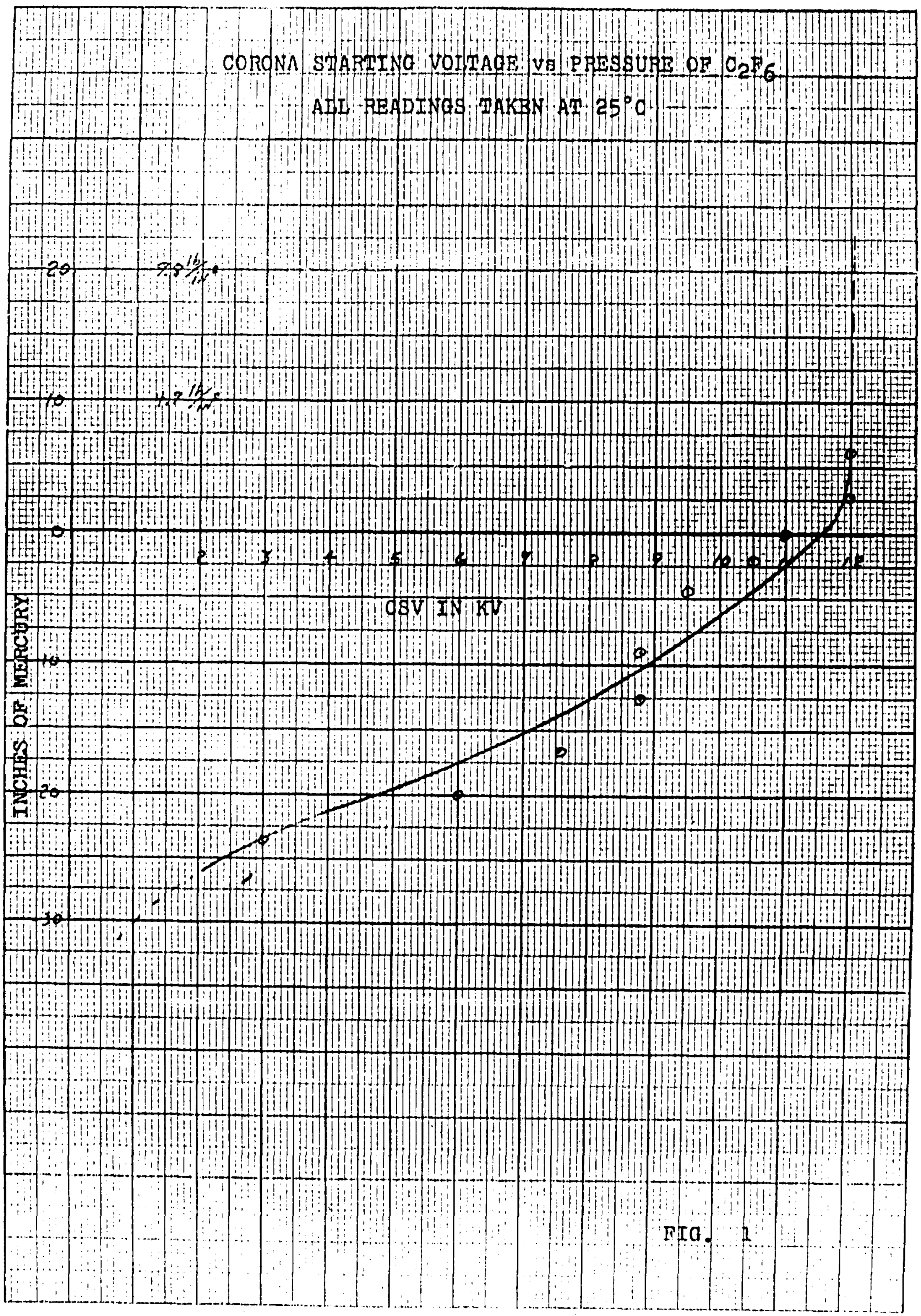
CORONA STARTING VOLTAGE vs PRESSURE OF C_2F_6
ALL READINGS TAKEN AT 25°C
CSV IN KV
INCHES OF MERCURY
29
10
0
10
20
30
2
3
4
5
6
7
8
9
10
11
12

FIG. 1

As the results of the above tests show, corona starting voltage falls below that required by the contract regardless of the atmosphere present in the void. Tests reported in the Sixth Quarterly Report show that corona starting voltage does meet the contract requirement when the unit is equipped with a reservoir to compensate for the volume change of FC-43 due to temperature variations.

Testing to date has shown that the corona starting voltage requirement is met only when the internal components of the network are completely submerged in the FC-43 impregnant; therefore, it will be necessary to employ some device which will be capable of compensating for the change of volume of FC-43 over the temperature range required by the contract. As reported in the Fifth and Sixth Quarterly Reports, volume-compensating bellows seem to be the answer to the problem of corona starting voltage.

2. Unit Equipped with Volume-Compensating Bellows

Volume-compensating bellows have been obtained and incorporated in test units. In order for the unit to include the bellows and still be contained within the overall case dimensions specified, it was necessary to redesign the internal components of the network itself. The coils have remained unchanged, but the capacitors have taken a different mechanical shape. The overall unit, although mechanically different, retains the same voltage stress and general assembly features (see Figures 2 and 3). To reduce the amount of compensation necessary,

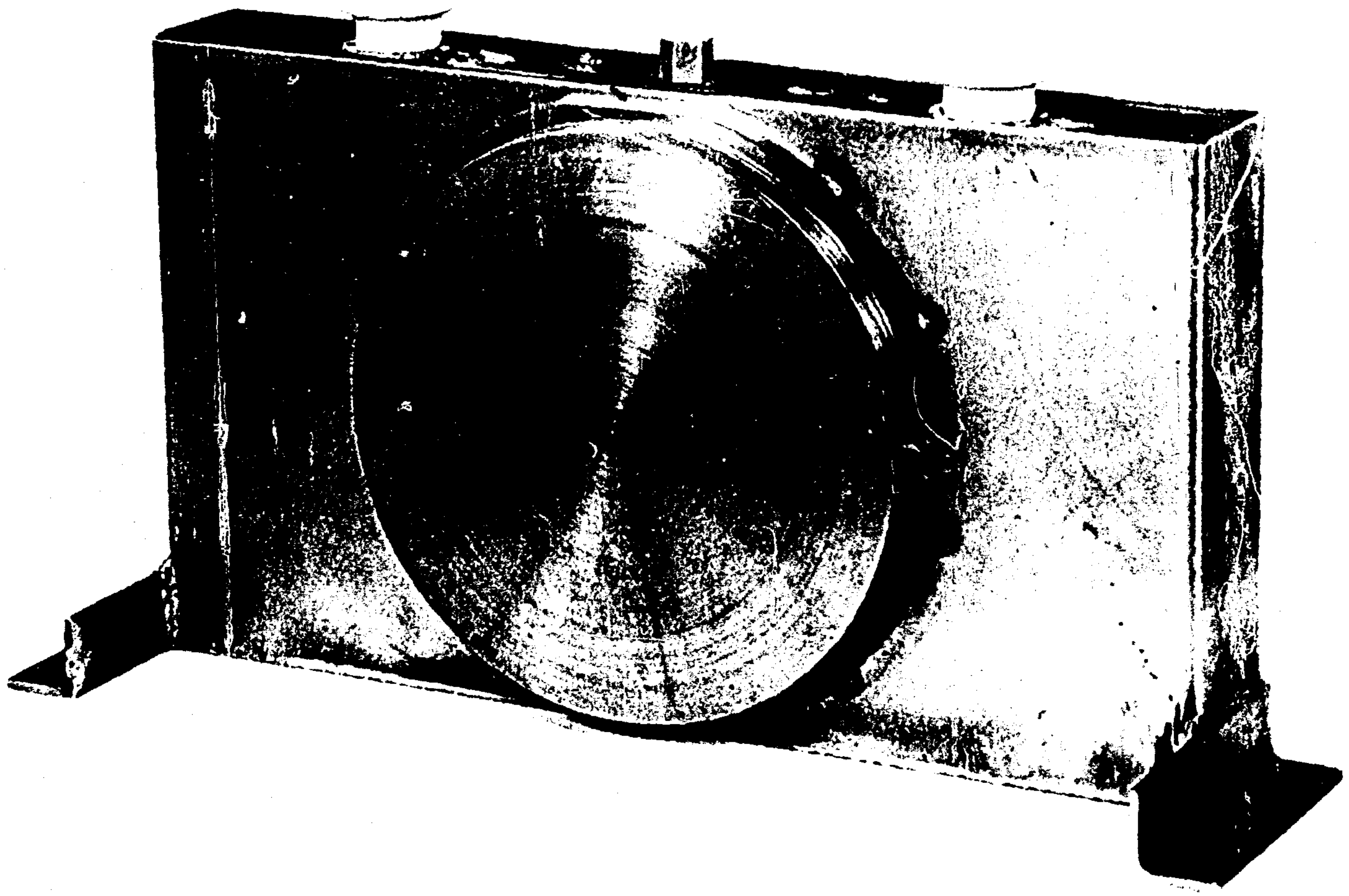

FIGURE 2

Completed Experimental Unit

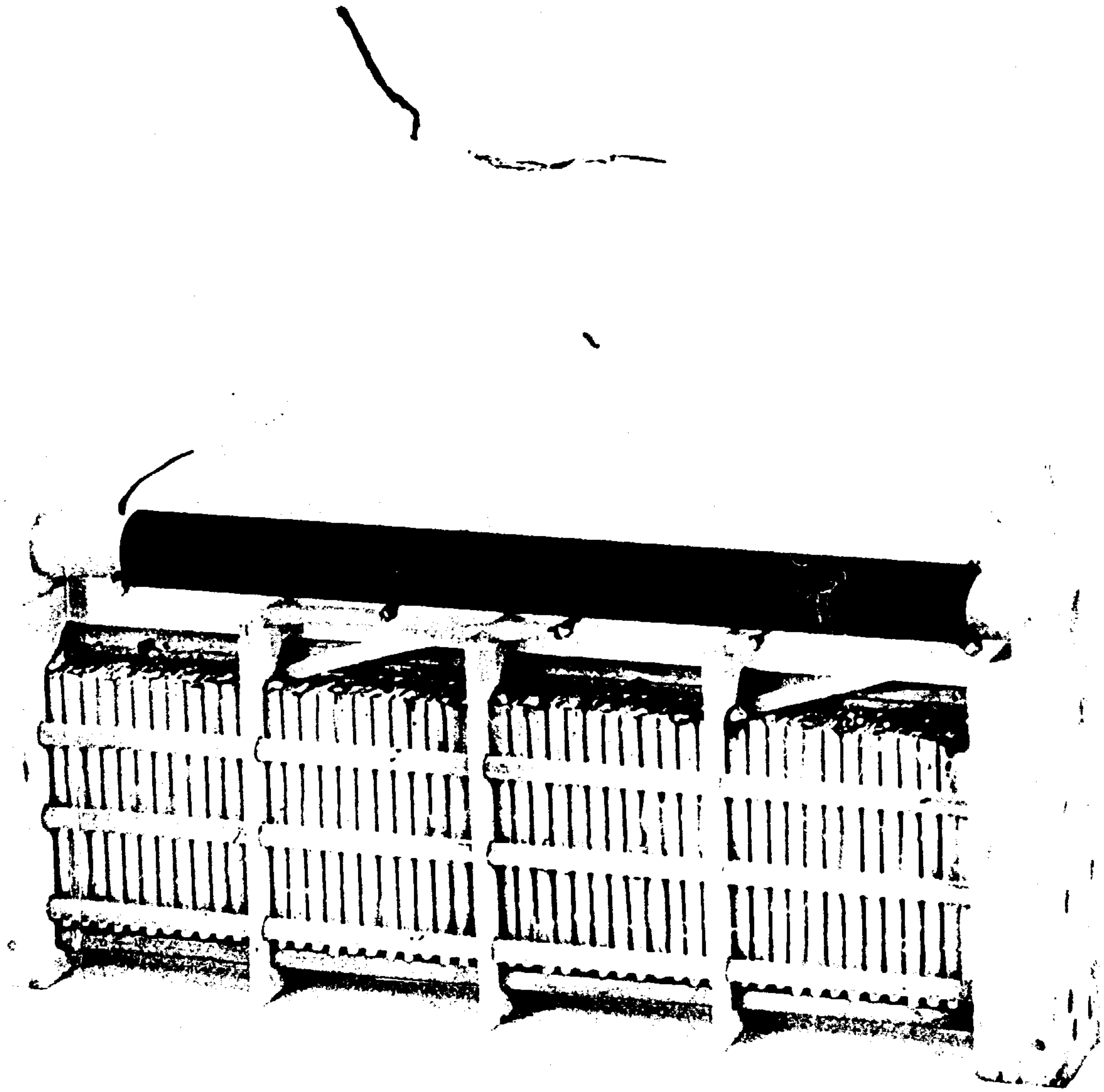

FIGURE 3

Internal Assembly of Experimental Unit

solid particles of Teflon were added to the impregnant, since, as reported in the Sixth Quarterly Report (Figure 1), percentage volume change due to increased temperatures is less for FC-43 filled with Teflon than for FC-43 alone.

(Figure 1 of the Sixth Quarterly Report also shows that FC-43 filled with glass beads has even less volume change due to temperature than does FC-43 filled with Teflon. The reason Teflon filling was chosen over glass filling was that the dielectric properties of FC-43 were nearer to those of Teflon than to those of glass.)

As can be seen in Figure 3, these Teflon particles occupied the voids located around the coil assembly and at the sides and bottom of the capacitor sections.

a. Corona Starting Voltage

During this period testing of units equipped with bellows began. As stated earlier, the primary purpose of the bellows was to solve the problem of corona starting voltage, since their use insured the complete submersion of components in impregnant.

The results of the corona starting voltage test performed are as follows:

Unit impregnated at -55°C with FC-43.

CSV at -55°C - clear at 15 KV RMS.

Unit heated to 25°C.

CSV at 25°C - clear at 15 KV RMS

Unit heated to 160°C.

CSV at 160°C - clear at 15 KV RMS.

Unit cooled to 25°C.

CSV at 25°C - clear at 15 KV RMS.

As the results of the above test show, the corona starting voltage requirements of the contract are met at all anticipated operating temperatures. During the above testing there was no voltage applied to the network during heating or cooling.

b. Twice-Rated-Voltage Test

Once it had been established that the bellows-equipped unit was capable of meeting the corona starting voltage requirements of the contract before electrical tests, the next step in testing was to place the unit in an ambient of 150°C and operate it at twice-rated voltage for 24 hours. In order to maintain an input power at twice-rated voltage equal to the input power at rated voltage, the load was reduced to 3/4 of the impedance of the network, and the pulse repetition frequency was reduced from rated (450 pps) to 112.5 pps.

This unit operated for 5.2 hours under the above conditions before failure. The failure was probably caused by the combination of temperature and dielectric stress at which the unit was operating.

At the time of failure the recorded case temperature was 189°C. Since the FC-43 impregnant boils between 170° and 180°C at atmospheric pressure, boiling of the impregnant probably occurred inside the unit. The boiling impregnant generated vapors which had an expanded volume many times that of the liquid from which they were generated. The bellows, being capable of compensating only for the liquid expansion, was extended beyond its elastic limit and ruptured.

In addition to the mechanical failure, there occurred an electrical failure. The electrical failure was also undoubtedly caused by the boiling with the resultant gas phase in the dielectric. As reported in the Sixth Quarterly Report, boiling impregnant within the capacitor sections causes drying of the sections, which in turn decreases the section insulating capabilities. The decrease in dielectric strength and the high stress to which the sections were exposed at twice-rated voltage caused the electrical failure to occur.

3. <u>Life Electric Tests</u>

Life testing of the small test units during this period has yielded several points which have been added to the curve showing voltage stress vs life. This curve (Figure 4) contains all accumulated data pertaining to life testing of this test design at 160°C.

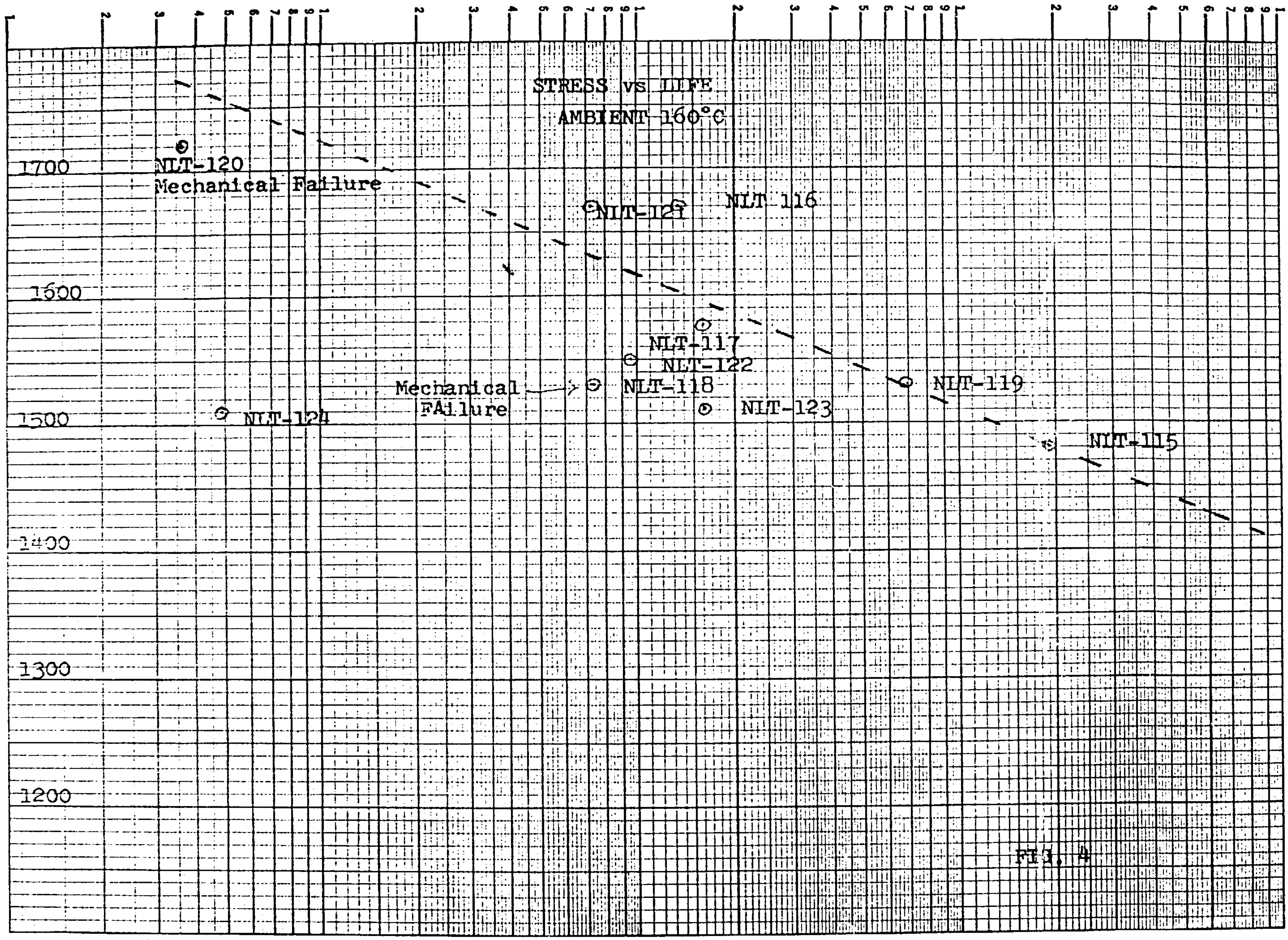
STRESS vs LIFE
AMBIENT 160°C
1700
1600
1500
1400
1300
1200
NLT-120
Mechanical Failure
NLT-121
NLT 116
NLT-117
NLT-122
Mechanical
FAilure
NLT-118
NLT-123
NLT-119
NLT-124
NLT-115

FIG. 4

C. Conclusions

The results of tests described in this report show that the corona starting voltage requirements of the contract are met only when some volume-compensating device is used to compensate for the expansion and contraction of the FC-43 liquid as the network is cycled through the temperature range required.

The volume-compensating bellows solved the problem of meeting the corona starting voltage requirements of the contract, but the problem of meeting the requirements of operation at twice-rated voltage at an ambient of 150°C remains unsolved.

Data obtained during life testing of small test units have indicated that final design stress will satisfactorily meet the specification of the contract. Failures in full-sized units at stresses which small test units have survived were caused by the pressures existing inside the tanks. Since the small test units were sealed off, increases in temperature created increases in pressures preventing boiling of the impregnant. The full-sized units equipped with volume-compensating devices are subjected to nearly constant pressures (near one atmosphere); therefore, boiling takes place inside the tank, and failure occurs.

PART II - FUTURE PROGRAM

Testing of units employing volume-compensating bellows will continue. These tests will be directed primarily at producing a unit that will operate at twice-rated voltage in an ambient at or near that required without causing internal temperatures leading to boiling of the FC-43 impregnant.